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Wearables for Long Term Gait Rehabilitation of Neurological Conditions

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Abstract

Many people with long-term neurological and neurodegenerative conditions such as stroke, brain injury, multiple sclerosis or Parkinson's disease suffer from an impaired walking gait pattern. Gait improvement can lead to better fluidity in walking, improved health outcomes, greater independence, and enhanced quality of life. Existing lab-based studies with

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wearable devices have shown that rhythmic haptic cueing can cause immediate improvements to gait features such as temporal symmetry, stride length and walking speed. However, current wearable systems are unsuitable for self-managed use, and to move this approach from out of the lab into long-term sustained usage, numerous design challenges need to be addressed. We are designing, developing, and testing a closed-loop system to provide adaptive haptic rhythmic cues for sustainable self-managed long-term use outside the lab by survivors of stroke, and other neurological conditions, in their everyday lives.

Author Keywords

Long-term; gait; tracking; wearables; adaptive; rhythm; health; entrainment;

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

Introduction

Conditions such as Stroke, Parkinson's disease (PD), Multiple Sclerosis (MS), Traumatic Brain Injury (TBI), and Acquired Brain Injury (ABI) can all cause motor impairment, affecting basic tasks like walking, standing

and reach. To improve individual health and well-being for patients it would be helpful to be able to both assess and treat their gait outside the clinic or lab. This would have the potential to allow researchers, clinicians, caregivers, and physiotherapists to devise and deliver more effective rehabilitation plans over the long-term [1]. Consequently, wearable sensing and feedback systems now offer considerable potential for the assessment and treatment of gait abnormalities over the long terms outside of clinical settings [2].

Gait Abnormalities and their Implications

Many survivors with motor impairment develop gait abnormalities, such as hemi-paretic, hemiplegic, diplegic, neuropathic and Parkinsonian gait [3]. The exact nature and effects of such gait abnormalities are varied; however, common results include bone degeneration, joint pain, increase in higher vertical forces in the legs, loss of bone mineral density and increased risk of falls and fractures [4]. Overall these factors cause reduced mobility, reduced quality of life, lack of confidence and independence.

Consequently, gait rehabilitation is a high priority for survivors of such conditions [5], though funding and availability for such therapy is often limited. Usually there are long gaps between physiotherapy sessions and therapists have no knowledge of their patients' compliance or progress during that period. Ability to track the progress of their patients is highly desirable for the therapists. Moreover, this can also empower the survivors with a tool to track their own progress.

Biological Entrainment and Rhythmic Cueing

Gait rehabilitation using rhythmic cueing can be performed via three sensory channels: auditory, visual

and haptic [6]. These modalities have all shown improvements in gait features in the lab, especially auditory and haptic. The principle behind rhythmic auditory cueing and rhythmic haptic cueing is primarily biological entrainment [7], and its interaction with the Neural Central Pattern Generator [8]. In outline, the regular sequence of cues acts as a template for the brain to entrain with [9] typically leading to improvements in certain gait features, in particular increased temporal symmetry of steps, increased stride length and speed of walking [7].

Rhythmic cueing based on audio stimuli is a proven method for improving gait via entrainment [10], but in practice, its use is generally limited to the lab [7]. The lack of use in outdoor settings seems to reflect the problem that auditory cueing can be distracting and isolating out of doors, where survivors typically need to remain safe and aware of the environment. Haptic cueing is of particular interest because it offers an unobtrusive, invisible, sociable, safe alternative [11]. Other potential advantages of the haptic modality include the ability to deliver cues to the appropriate leg at the appropriate time, taking advantage of the proprioceptive and kinaesthetic senses [7,12]. However, existing systems that combine gait tracking and adaptive haptic cueing are unsuitable for long-term self-managed use outside the lab.

Long-term Gait Tracking

In order to better understand the challenges of moving this technology to self-managed outdoor and long-term use, we carried out what is to the best of our knowledge the first longitudinal pilot study (Figure 1) on the self-managed use of wearable haptic devices for gait rehabilitation via entrainment in outdoor settings.



Figure 2: An off-the-shelf wearable haptic device, worn on the wrist, to give rhythmic haptic cue for walking outdoors [13].

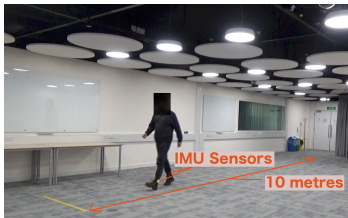


Figure 3: Data collection in-lab using IMU sensors on both ankles. The participant was asked to walk 10 metres in a straight line for for 6-8 times.

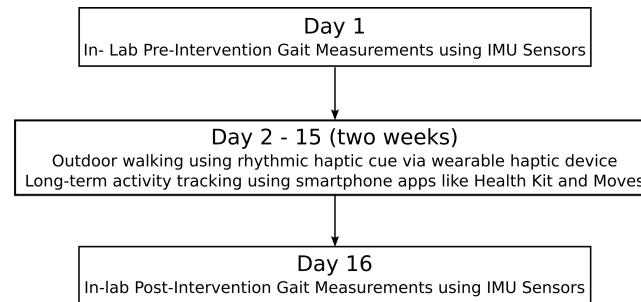


Figure 1: Pilot Study Design. The study consists of 3 stages: Day 1 – Pre-Intervention gait measurements, Day 2-15 (two weeks) – Outdoor walking and long-term tracking, Day 3 – Post-Intervention gait measurements.

The study involved a brain injury survivor who had reduced ability on both sides of his body and therefore, significant gait impairments. On Day 1 of the study, we measured his baseline pre-intervention baseline measurements in the lab (Figure 3) using x-OSC inertial measurement units [14] on both ankles. The measurements were taken while walking 10 metres in a straight line for about 6-8 times. The IMU data was logged wirelessly to a laptop for later analysis. While he was walking in the lab, he was also video recorded to later show it to physiotherapists to evaluate his gait.

Using data obtained from the IMU, we have calculated the participant's mean walking cadence and used it as a reference for the haptic cueing rhythm, that he would have to follow while walking outdoors for about two weeks. The participant was asked to walk in synchrony to the haptic rhythm at a suitable outdoor setting for at least five minutes for about 10 days within two weeks.

To provide the haptic cue for previous in-lab studies, we have used a family of wearable haptic devices developed in-house, generally known as the Haptic Bracelets [15], however, for this longitudinal pilot study we have provided a commercial off-the-shelf wearable device (Figure 2) that can provide rhythmic haptic cue only. In addition, the participant was also provided with an iPhone running the Health Kit [16] and Moves [17] applications, recording their step count, walking distance, duration and route. Moreover, the participant maintained a diary logbook to record the start and end times for his walks. He was asked to carry the iPhone, wear the wearable haptic device and turn on the rhythm only when walking outdoors.

After the two-week period, he returned to the lab and gait measurements were taken again using IMU sensors, similar to Day 1. He was also asked a number of interview questions related to usability, wearability, compliance, challenges he faced and perceived changes in his gait.

Evaluation

The participant was trained on how to wear the wearable haptic device, how to use it to produce the rhythm, how to follow the rhythm to synchronise walking, how to carry the iPhone, how to charge these devices and how to maintain the diary logbook. Overall, the participant was able to perform all these tasks comfortably and compliance for the study was satisfactory. The participant took 15 walks during the two-week period which hints a sense of eagerness and enthusiasm from his part.

On comparing data from Day 1 pre-intervention with Day 16 post-intervention gait measurements,

significant improvements in gait characteristics was observed. In addition, expert gait evaluation by a physiotherapist have also showed significant improvements on the following gait characteristics: stride length, temporal symmetry and walking speed. The long-term tracking data also conform the in-lab measurements and the evaluation of the physiotherapist.

Design Implications

This study also revealed numerous design challenges related to long-term design for users with characteristics such as reduced dexterity, hemiparesis, reduced sensitivity and limited proprioception.

Design aims for long-term use include simplicity, wearability, unobtrusiveness, low maintenance, low cost, oversight, where appropriate, by clinicians, accuracy and completeness of the longitudinal data.

For this pilot study, neither the participant nor the researchers had access to the data during two-week period. As an extension to this study, we are planning to provide a customised wearable device, that will provide the haptic rhythm and also be able to track activity and compliance over the long-term. Another addition to the system in the future would be sensors attached to the ankles or feet, to monitor real-time gait and feedback to the system to provide adaptive cueing. The data would also be provided to the clinicians and physiotherapists to monitor progress. The possibility for the patients to monitor their own progress needs to be further explored, as our initial studies have shown limited interest in this regard.

Conclusion

We believe that wearable systems able to both assess and, where appropriate, treat gait outside the clinic or lab over the long-term have the potential to make a substantial contribution to the gait rehabilitation of survivors of neurological conditions. The design of these systems will need to be adapted to be suitable for a combination of self-management and therapist-overseen use. At present, most stroke survivors, for example, do not receive any rehabilitative therapy at all beyond a few weeks after their stroke, as continued gait training is very expensive.

Thus, such a system for community ambulators, where real time continuous gait data is collected over extended periods, in parallel with the provision of adaptive haptic rhythm, has potential to act as a highly desirable self-managed physiotherapy mechanism beyond care homes and indoor physiotherapy sessions.

Remote long-term gait tracking and training can lead to many benefits, most importantly improved confidence and independence, and improved quality of life and well-being, additionally reduction of costs associated with care and rehabilitation.

Such a system may be beneficial for post-operative progress tracking for knee and hip surgery patients and in addition, gait tracking of athletes, runners, and professional sportspersons.

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